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RESEARCH MEMORANDUM

A NEW MODEL FOR FALLOUT CALCULATIONS (U)

R. R. Rapp

RM-2115

13 February 1958 Copy No._____

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SUMMARY

This paper presents a new model for the machine calculation of fallout patterns. The model is divided into three parts: (1) meteorological, which considers wind velocity and the fall velocity of the particles; (2) geometric, which considers distribution of activity on particles in the cloud as a function of height and particle size; and (3) radiological, which considers the radiation doses of particles on the ground. The use of the model is illustrated, and the changes in the model that will provide an optimum model (currently being developed) are discussed.

CONTENTS

SUMMARY iii

Section
I. INTRODUCTION 1

II. FIRST MACHINE MODEL 5

III. THE NEW MODEL 11
General 11
The Meteorologic Calculations 11
Errors in Meteorological Part 15
Geometric Part 18
Preliminary Estimates of the Distribution Functions 20

IV. DISCUSSION 27

V. CONCLUSIONS 31

APPENDIX
Meteorological Data 33
Geometric Data 36

REFERENCES 45

AFSWP DISTRIBUTION LIST 47

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RAND RESEARCH MEMORANDUM

A NEW MODEL FOR FALLOUT CALCULATIONS (U)

R. R. Rapp

RM-2115 February 13, 1958

in brief

A new model for the machine calculation of fallout described in this Research Memorandum is the latest result of research which began at RAND in 1952. An earlier model to explain the observed facts of radioactive fallout was described in other publications (RM-1855, RM-1371, R-265-AEC, and R-309). The present Research Memorandum describes a new and more flexible computational model to investigate the effect of variations of input data and to discover the effect of parameters. The model is divided into three parts: meteorological, geometric, and radiological.

The initial test of the model was made with the fragmentary Castle-Bravo wind data. The feasibility of the approach has been shown, and the accuracy of the model within the limits of the available data has been verified. The next set of data processed can proceed on the assumptions that:

1. small changes in the distribution functions will produce only negligible changes in the pattern;
2. the wind patterns are sufficiently accurate to put limits on the possible distribution functions;
3. the gross effects of the fallout from large-yield shots are not affected by stem material.

It may be inferred that most of the radioactive material is lodged on particles in a very narrow range of sizes and that it is concentrated into a very narrow range of heights at the time of stabilization.

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I. INTRODUCTION

The process of developing a model that will adequately explain the observed facts of radioactive fallout was begun at RAND in the fall of 1952. The physical process described in reference (1) was the result of those early investigations. The simple mathematical model[(1)] and the subsequent work of other investigators[(2)] served to confirm the validity of the approach to the problem. Procedures were devised for hand computation[(3)] and machine computation[(4)] which further confirmed the basic principles but also served to show that there were deficiencies in the input data. To investigate adequately the effect of variations of input data and to discover the effect of variation of parameters a new, more flexible computational model was needed. This report deals with the development of such a model.

Before presenting the development of the new model it may be profitable to review briefly the physical concepts and the first machine model. To describe the phenomenon of fallout, we must begin with the nuclear detonation. The main distinguishing feature of a detonation of this type is a tremendous release of energy almost instantaneously and within a very small space. This release of energy creates a hot bubble of air which rises because of its bouyancy. The characteristic mushroom-shaped cloud associated with nuclear explosions is formed by water vapor condensed as a result of vertical lifting. The temperature gradient between the hot bubble and the surrounding atmosphere causes a strong toroidal circulation.

Fission fragments, together with any other debris mixed into the fireball at an early stage, are carried aloft, and as the cloud rises some of the material may be left behind, forming a wake or stem. The cloud will stop rising when the energy available to lift it has dissipated. At this time

(from 4 to 6 minutes), which is referred to as the time of stabilization, the spatial distribution of the radioactivity provides one set of the initial conditions required in the fallout model.

Within this stabilized cloud are virtually all the fission products formed by the nuclear detonation and, in some cases, by induced activity. Radioactive particles may be formed by condensation of vaporized material or by the coalescence of fission products with solid or liquid earth particles. The size of the particles is determined largely by the initial conditions of the burst; if little solid material is taken into the cloud, the particles will in all likelihood be small; if, conversely, the device is detonated on or near the surface, many tons of earth will be swept into the cloud, and a sizeable fraction of the fission products will be contained in large particles. The size of the particles containing radioactive elements has an important bearing on the fallout problem. The radioactivity located in or on large particles will be brought rapidly to the ground, while that lodged in small particles will remain suspended in the atmosphere for long periods of time. Another of the initial conditions required in the fallout model, therefore, is the distribution of activity with particle size within the stabilized cloud.

Given the stabilized cloud and the associated distribution of activity with particle size and in space, it is necessary to determine the position of the active particles after they fall to the ground. The rate of fall is of primary importance here, and an aerodynamic law of fall which takes into account, by means of drag coefficients, inertial as well as viscous forces was used.

As the particles start to fall through the atmosphere, they will be

carried by the wind. There are a great many wind effects which have to be taken into account. First, the whole cloud will be moved bodily by the mean wind at the cloud level. At the same time, there will be shearing effects due to the variation of the wind with altitude, and there will be turbulent effects, small scale eddies, which will tend to spread and tear the cloud.

The necessary elements of a fallout model may be summarized:

1. Distribution of activity with space
2. Distribution of activity with particle size
3. Fall velocity
4. Wind structure

II. FIRST MACHINE MODEL

The first machine model used at RAND is reported in detail in reference (4). The cloud was assumed to be a cylinder with a uniform distribution of activity in the horizontal (Fig. 1) and an exponential decrease from the base of the cloud upward (Fig. 2). This decrease with height was predicated on the assumption that the number of active particles per unit mass of air is constant in the mushroom. The uniform horizontal distribution is the most simple of all possible distributions. The distribution of activity with particle size is based on a distribution which reproduced the fallout pattern of the Jangle Surface shot (Fig. 3).

In the model, particles were chosen to represent the fallout at every 1000 ft of elevation at the center of the cloud for values of particle size which divided the activity size distribution into 100 equal intervals. Thus for each elevation, each particle size represented the same amount of activity. The turbulent effects were ignored and the ground position of each particle from each elevation was assumed to represent the center of a circle whose radius was equal to the radius of the stabilized cloud. The activity at a point was calculated by adding the contributions from those circles which contained the point. This system of calculation is fairly efficient insofar as machine time is concerned; however, the method requires a complete recoding for a change in the model because the meteorology is connected to the geometric and particle-size parameters through the choice of particle sizes to be used. The new computation scheme should permit variations of some parts of the model without changing others.

Another feature of the first computation scheme was the incorporation of the decay scheme into the procedure. The activity was assumed to decay

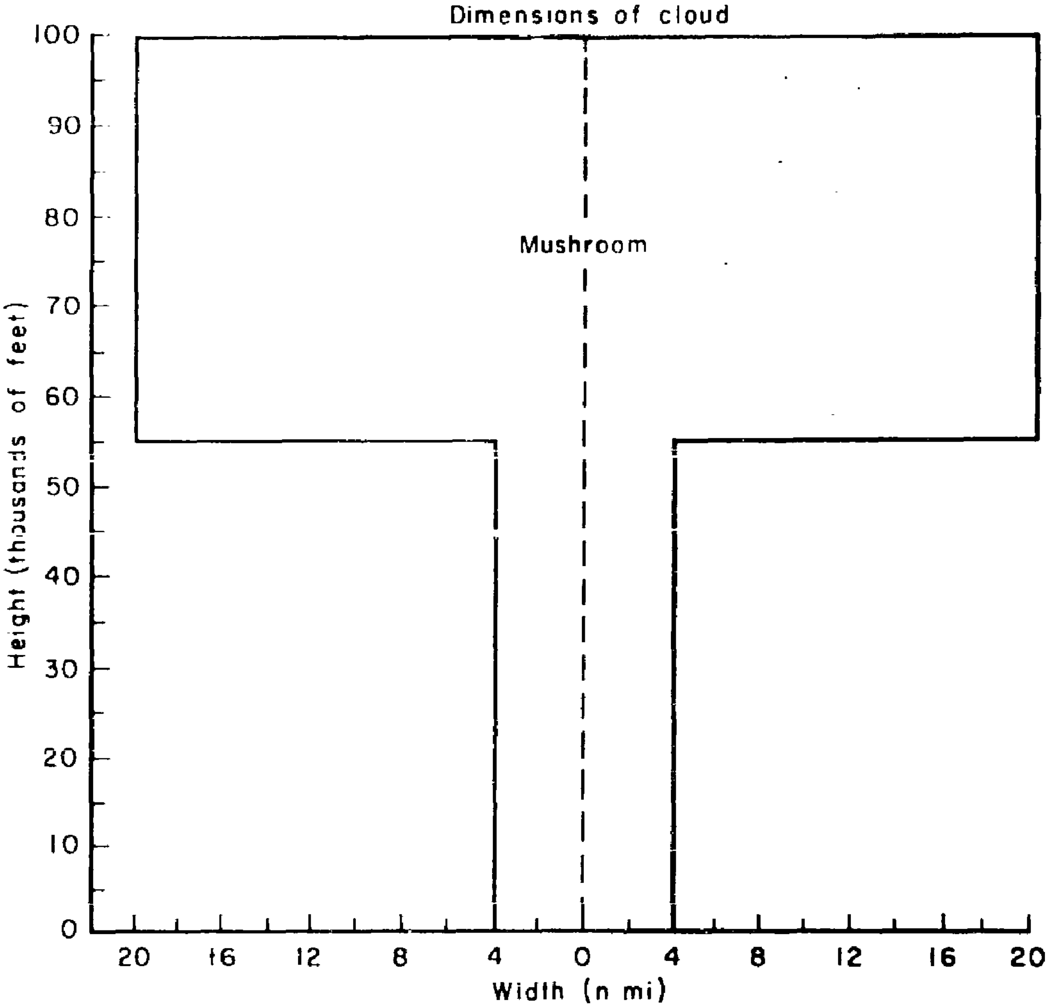

Fig. 1 — Assumed geometry of a cloud resulting from a large-yield nuclear detonation
(As used in the first RAND machine model)

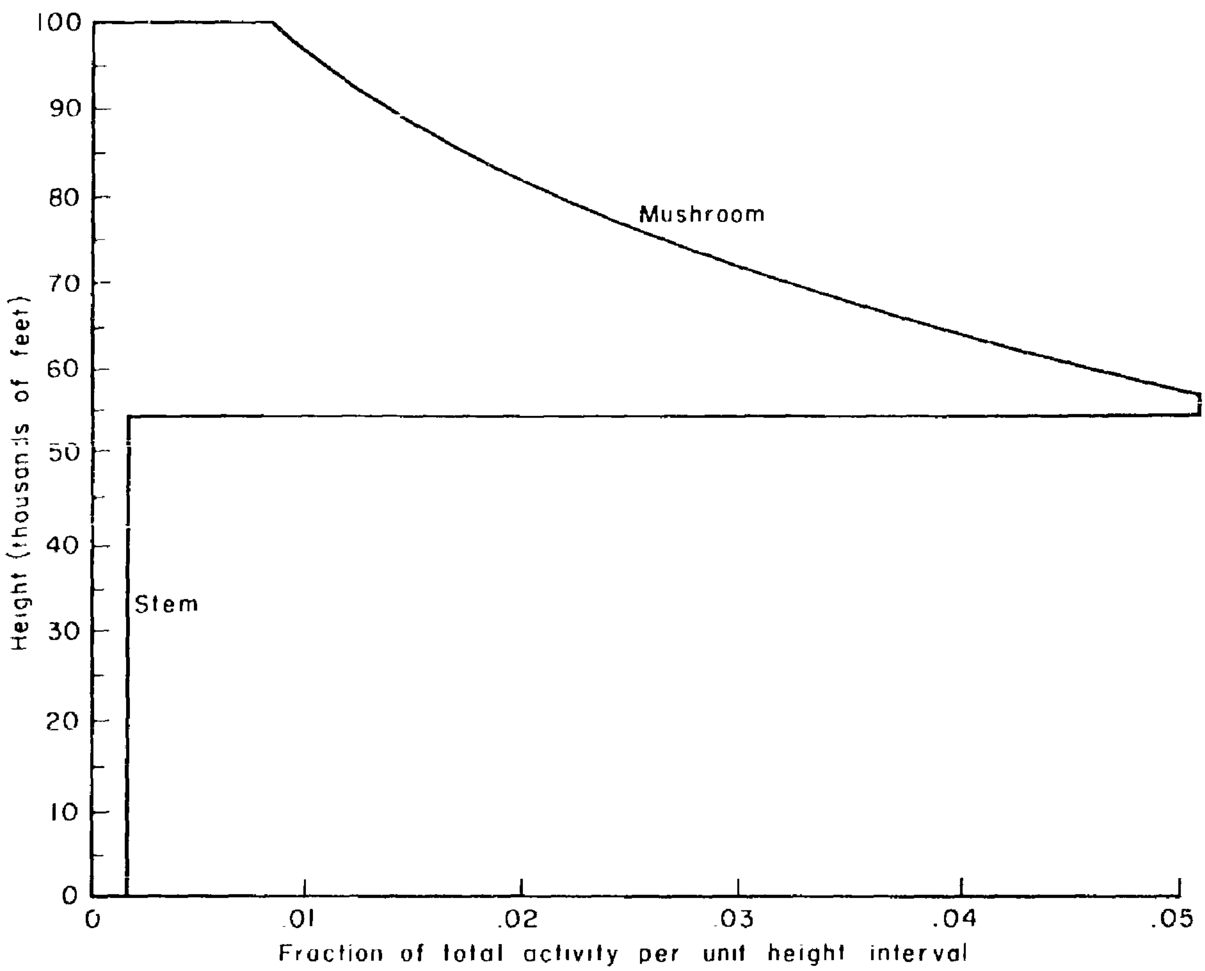

Fig. 2—Assumed distribution of radioactivity in space following a large-yield nuclear detonation

(As used in the first RAND machine model)

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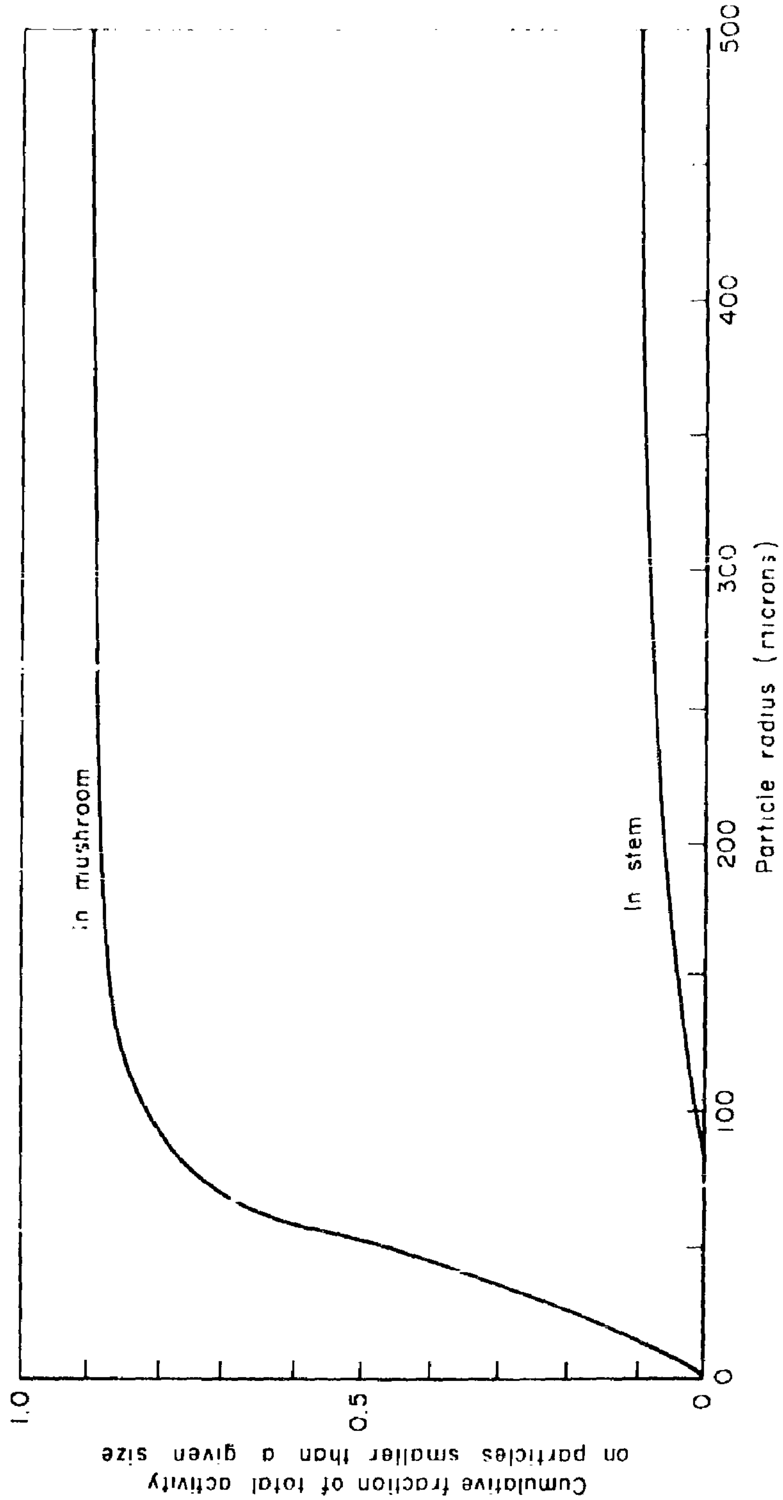

Fig. 3—Cumulative distribution of radioactivity with particle size

(As used in the first RAND machine model)

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with the $t^{-1.2}$ law, and the results were transformed to dose rates and integrated doses. While this scheme worked well for fission devices, the variability introduced by clean and salted weapons makes it important to separate the radiological effects from the calculations of particle deposition.

III. THE NEW MODEL

A. General

In order to insure flexibility in the new method of computing fallout,* the problem was separated into three component parts. The first part, called the meteorological part, is the determination of the positions on the ground of a fixed set of particles starting from fixed heights in the atmosphere. There are only two sets of the basic variables introduced in this section of the computations, i.e., the fall speed and the velocity of the wind. The second section, which is referred to as the geometric part, is a method for determining the surface density as a function of the density of the stabilized cloud, using the ground distribution of particles. This section involves the distribution of activity with height, radius, and particle size. The third part, which is called the radiological part, deals with the analysis of the radiation dosages that are received from the distribution of activity on the ground. Due to the variable nature of the radiological products no attempt will be made, in this model, to compute radiological effects on the ground.

B. The Meteorologic Calculations

The ground position of a particle falling with a velocity w(r,h) through a wind field W(x,y,h,t) is given by

$$D = \int_0^H \frac{W(x,y,h,t)}{w(r,h)}\, dh$$

*In contrast to the first model which was run on the IBM-702, the second model was programmed for and run on the IBM-704 with an augmented memory.

For numerical work this can be expressed as a sum and divided into two component parts

$$X = \sum_{i=o}^{m} \frac{V_{xi}(x,y,h,t)}{w_i(r,h)} \Delta h_i$$

$$Y = \sum_{i=o}^{m} \frac{V_{xi}(x,y,h,t)}{w_i(r,h)} \Delta h_i$$

The fall velocities are computed by the aerodynamic methods outlined in the references mentioned.(1-4) A detailed analysis of the problem of fall velocities will be the subject of another report.(6) It is sufficient here to state that aerodynamic rates for spheres have been used in accordance with the results of the experiments reported in reference (5). The values of the fall speeds are presented in Fig. 4.

It has been shown(4)(7) that the time and space variations of the wind are important in predicting fallout, and therefore the model must be able to account for time and space variations. The wind field is really a three-dimensional vector field which is continuous in time and space. To properly take this into account, continuous functions should be used. Unfortunately measurements of the wind field give discrete values of the horizontal component at discrete times. The vertical component cannot be directly measured by any instrument, but it is known to be small compared to the horizontal component. The vertical component will be neglected because it cannot, with current techniques, be calculated with sufficient accuracy.

The east-west and north-south components of the horizontal wind can be measured and will be used separately. Thus, if V_α represents one of these components, it can be measured at discrete intervals of space and time. In

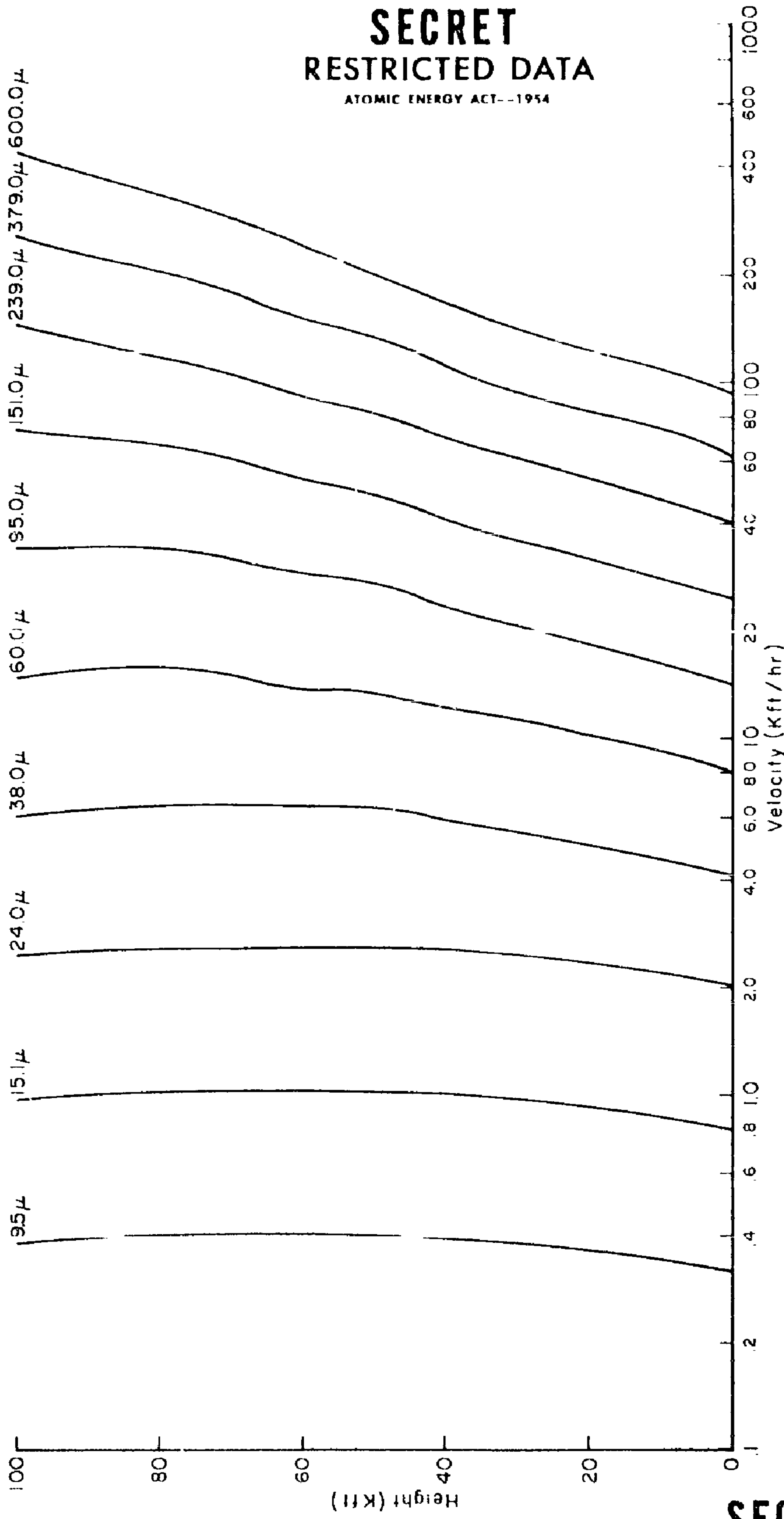


Fig.4—Fall velocity as a function of height and particle radius

order to estimate the wind affecting the particle at any point and at any instant, a four dimensional linear interpolation scheme will be used.

Suppose at time t, the particle is at a height H, at the position ij. Let $V_{\alpha ijkn}$ represent the velocity component in the α direction at the point ij, the height k, and the time n. If there are three points where the wind is known at two times and at intervals of 5000 ft, a first interpolation can be made in elevation:

$$V_{\alpha ijon} = V_{\alpha in-1n} + \frac{H_o - H_{-1}}{H_1 - H_{-1}} \left(V_{\alpha ij1h} - V_{\alpha ij-1n}\right) \tag{1}$$

The next interpolation is for position and is given by

$$\begin{aligned} V_{\alpha oo} = V_{\alpha 33} + \frac{1}{D} \Big\{ & x \;\; (y_1 - y_2)(V_{\alpha 33} - V_{\alpha 11}) - (y_1 - y_3)(V_{\alpha 22} - V_{\alpha 11}) \\ & + y \;\; (x_1 - x_3)(V_{\alpha 22} - V_{\alpha 11}) - (x_1 - x_2)(V_{\alpha 33} - V_{\alpha 11}) \\ & + x_3 (y_1 - y_3)(V_{\alpha 22} - V_{\alpha 11}) - (y_1 - y_2)(V_{\alpha 33} - V_{\alpha 11}) \\ & + y_3 (x_1 - x_2)(V_{\alpha 33} - V_{\alpha 11}) - (x_1 - x_3)(V_{\alpha 22} - V_{\alpha 11}) \Big\} \end{aligned} \tag{2}$$

where $D = (x_1 - x_2)(y_1 - y_3) - (x_1 - x_3)(y_1 - y_2)$ and "...on" is assumed to be added to the subscripts of all the V's.

The final interpolation is in time and is given by

$$V_{\alpha 0000} = V_{\alpha 000-1} + \frac{t_o - t_{-1}}{t_1 - t_{-1}} \left(V_{\alpha 000-1} - V_{\alpha 0001}\right) \tag{3}$$

If this is done for both components x and y, then the velocity at the position of the particle is determined.

With this interpolation process, a particle is started from ground zero, the wind components are computed from Eqs. (1), (2), and (3). These winds are multiplied by a thickness Δh and divided by the mean fall velocity

in the layer; this yields a new position (x,y). The above process is repeated with this new position and a new change in position is computed. The process is repeated until the particle reaches the ground. A total of 7500 particle-height combinations are traced to the ground in this manner.

The time required for a given particle to reach the surface from a given height is also computed from the formula

$$t_d = \sum \frac{\Delta h}{w(r,h)} \tag{4}$$

The ground position and time-down for each particle from each height is stored on a tape so that the wind system can be used to check variations in geometry which might arise from variations in yield or burst conditions.

C. Errors in Meteorological Part

It is perhaps worthwhile to form some sort of estimate of the accuracy which may be obtained in the meteorological part of the problem. In order to make this estimate a great many simplifications will be made so that the estimates will yield only the order of magnitude of the wind error.

There are several major assumptions which need to be made in this analysis:

1. Wind errors $\epsilon(c, \sigma_\epsilon)$ are distributed according to a circular normal distribution with zero mean and a variance of σ_ϵ^2.

2. The variance of the errors is not a function of elevation.

3. The correlation of errors is a function only of the separation between winds and decreases rapidly with height difference.

4. For the purposes of this error analysis only, the fall velocities will be approximated by $W = W_o(r)e^{\alpha h}$.

5. The fall velocities are correct, and no vertical air motion occurs.

Now the calculated position of a given particle will be its actual position plus the integral of the error term

$$\mathbb{D}_e = \mathbb{D}_a + \int_0^H \frac{\epsilon(o,\sigma_E)}{W(r,h)}\,dh \tag{5}$$

According to assumption 1, $\bar{\epsilon} = o$, and $\bar{E} = o$ but σ_E must be calculated from

$$\sigma_E^2 = \int_0^H \int_0^H \frac{(\overline{\epsilon_1 \epsilon_2})}{W(h_1)\,W(h_2)}\,dh_1\,dh_2 \tag{6}$$

with assumption 2 above this becomes

$$\sigma_E^2 = \sigma_\epsilon^2 \int_0^H \int_0^H \frac{\rho_{12}(\Delta h)}{W(h_1)\,W(h_2)}\,dh_1\,dh_2 \tag{7}$$

where ρ_{12} is the correlation of errors with height. Now in accordance with assumption 3, $\rho_{12} = e^{-\beta\Delta h}$, where β is of the order of 1/2. This means that the correlation is less than 0.1 for separations greater than 5000 feet. According to assumption 4, $W(r,h) = W_1(r)\,e^{\alpha h}$, where the largest values of α, for 500μ particles, is about 0.016. Thus β is an order of magnitude greater than α.

Inserting these values in Eq. (7)

$$\sigma_{rE}^2(h) = \frac{\sigma_\epsilon^2}{W_o(r)} \int_0^H \int_0^H \frac{e^{-\beta(h_1 - h_2)}}{e^{\alpha h_1}\,e^{\alpha h_2}}\,dh_1\,dh_2 \tag{8}$$

where the subscript r has been added to the notation for the error variance to indicate that r is treated as a parameter. By making a change of variables

$$t = h_1 - h_2$$

$$s = h_1 + h_2$$

Eq. (8) becomes

$$\sigma_{rE}^2 = \frac{\sigma_E^2}{W_o(r)} \int_0^H \int_{-t}^{2H+t} e^{-(\beta t + \alpha s)}\, ds\, dt \tag{9}$$

Which, upon integration, becomes

$$\sigma_{rE}^2 = \frac{\sigma_E^2}{\alpha W_o^2(r)} \left\{ \frac{1}{\beta-\alpha} \left(1 - e^{-(\beta-\alpha)H}\right) - \frac{e^{-2\alpha H}}{\beta + \alpha} \left(1 - e^{-(\beta+\alpha)H}\right) \right\} \tag{10}$$

Now if β is of the order of 0.5 and α is of the order of 0.01, and if H is greater than 10 kilofeet, the terms $e^{-(\beta-\alpha)H}$ and $e^{-(\beta+\alpha)H}$ are small compared to 1 and $\beta-\alpha$ and $\beta+\alpha$ are very nearly equal to β. Therefore, for $H > 10$ kilofeet

$$\sigma_{rE}^2 \approx \frac{\sigma_\ell^2}{\alpha\beta\, W_o^2(r)} \left(1 - e^{-2\alpha H}\right) \tag{11}$$

Equation (11) was used to evaluate the ratio of σ_{rE} to σ_ℓ for a few values of r and H in order to provide a means of estimating the expected errors in a fallout pattern. These are shown in Table 1.

Table 1

Ratio of σ_{rE}/σ_ℓ as a Function of Height and Particle Radius

H (kf)	r (μ) 24	60	151	600
10	3.101	.747	.243	.063
20	4.160	1.023	.326	.084
30	5.000	1.196	.375	.095
40	5.633	1.321	.412	.105
60	6.578	1.506	.464	.114
80	7.272	1.628	.491	.118
100	7.883	1.701	.512	.118

D. Geometric Part

The meteorologic part of the problem provides a method for determining the ground position of many particles originating on many heights over ground zero. If an additional assumption is made, namely some law for the distribution of particles in the horizontal, the ground positions of many particles from many positions in the cloud could be determined. If a fraction of activity per unit volume per unit particle size can be assigned as a function of position in the cloud, then it is possible to determine the fraction per unit area in the fallout pattern.

The first simplification that will be made is to assume that the distribution is radially symmetric about the ground zero position. A second simplification is to assume that turbulent diffusion is not important, so that a particle at a distance R from the ground zero in the cloud would strike the ground at a distance R from the position of a particle of the same size originating over ground zero in the fallout pattern.

Let $A(R,H,r)$ be the fraction of the device per unit volume per unit particle size in the cloud at stabilization. Since A is a fraction or proportion

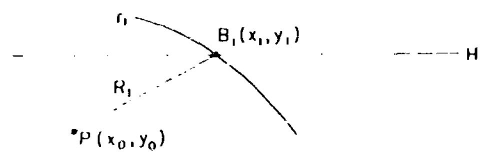
$$1 = \int_0^{2\pi} \int_0^{R_{max}} \int_0^{H_{max}} \int_0^{r_{max}} A(R,H,r)\, dR\, dH\, dr\, d\theta \qquad (12)$$

Since the function of three variables is rather intractable it will also be

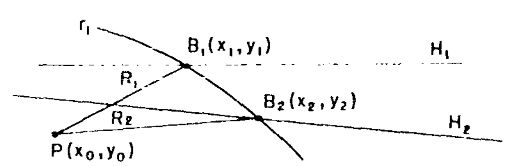
assumed that

$$A(R,H,r) = A_1(r)\ A_2(H)\ A_3(R) \tag{13}$$

To determine the surface density, consider an arbitrary point $P(x_0, y_0)$ in this fallout pattern. Near this point P there will be found the position of a particle size r_1, falling from a height H_1; call this point $B_1(x_1, y_1)$



With the assumption that the cloud composed of particles of size r_1 is not distorted by turbulence, the particles of size r_1 from height H_1 that land at P will come from a point $R_1 = \sqrt{(x_1-x_0)^2 + (y_1-y_0)^2}$ distant from the center of the cloud. The volume concentration due to this particle size and this height at the point P is therefore given by $A_1(r_1)\ A_2(H_1)\ A_3(R_1)$. Now in a similar way the particle size r_1 may fall from a height H_2 at the point $B_2(x_2,y_2)$ and have a volume concentration of $A_1(r_1)\ A_2(H_2)\ A_3(R_2)$



Now all of the particles r_1 from H_1 to H_2 will land at P with radii lying between R_1 and R_2 so that the integration of the activities as determined by the products $A_1A_2A_3$ between H_1 and H_2 will give the surface density of activity at P from particles of size r_1. A similar argument for another particle size r_2 will yield a surface density due to particles of size r_2. If the integration is performed over particle size from r_1 to r_2, the result is the fraction of the device per unit area contributed by all particles between r_1 and r_2 from heights between H_1 and H_2. If the integration is extended over all r and all H, the total fraction down at P is obtained. The fraction-down per square kilofoot is calculated for a set of pre-chosen grid points P.

It is interesting to note that the geometry of the cloud is expressed by the two distribution functions $A_3(R)$ and $A_2(H)$. At large distances, A_3 reduces to zero and no contribution is made; this continuous distribution is contrasted with the cooky-cutter technique of the first RAND model. The errors introduced through the distribution functions can best be handled by a variation of parameter techniques. Thus several runs may be made using different "A" functions with the same wind patterns, in order to estimate the accuracy of the geometric part.

E. Preliminary Estimates of the Distribution Functions

In an attempt to delineate the distribution of the radioactivity in a stablizied cloud, rockets were shot through some of the Redwing clouds at 7 minutes after detonation. The initial estimates of kiloroentgens per hour at 7 minutes was published in ITR-1354.[8] It is hoped that, when final reports are prepared, all of the data will be useful. Until such time, the Zuni data will be used to obtain a preliminary estimate of the

distributions.

The Zuni rockets passed very nearly over ground zero and therefore were assumed to represent a vertical plane through the diameter of the cloud. In order to further simplify the problem circular symmetry about ground zero will be assumed. The data were then plotted at the appropriate height and distance from ground zero and smooth contours of the reported rocket readings were drawn (Fig. 5).

From the smoothed contours, the total activity in the cloud was computed by a numerical integration. From the total activity and the smooth contours, the fraction of activity per cubic kilofoot was computed as a function of height and radial distance is shown in Table 2.

The estimate of $A_2(H)$ was chosen as the marginal distribution which is obtained from the numerical integration of R A(R,H) dR at several different heights. This distribution is shown in Fig. (6). The estimate of $A_3(R)$ was chosen as the integration of A(R,H) dH for several different values of R. Figure (7) shows this distribution.

The distribution of activity with particle size was chosen as the distribution presented in reference (1). Accumulative distribution was plotted; points were read from the cumulative function; and numerical differentiation was used to determine values of $A_1(r)$. Since this is a badly skewed distribution, it is convenient to use as a variable ln(r) instead of r. Figure (8) shows the activity as a function of size for this distribution.

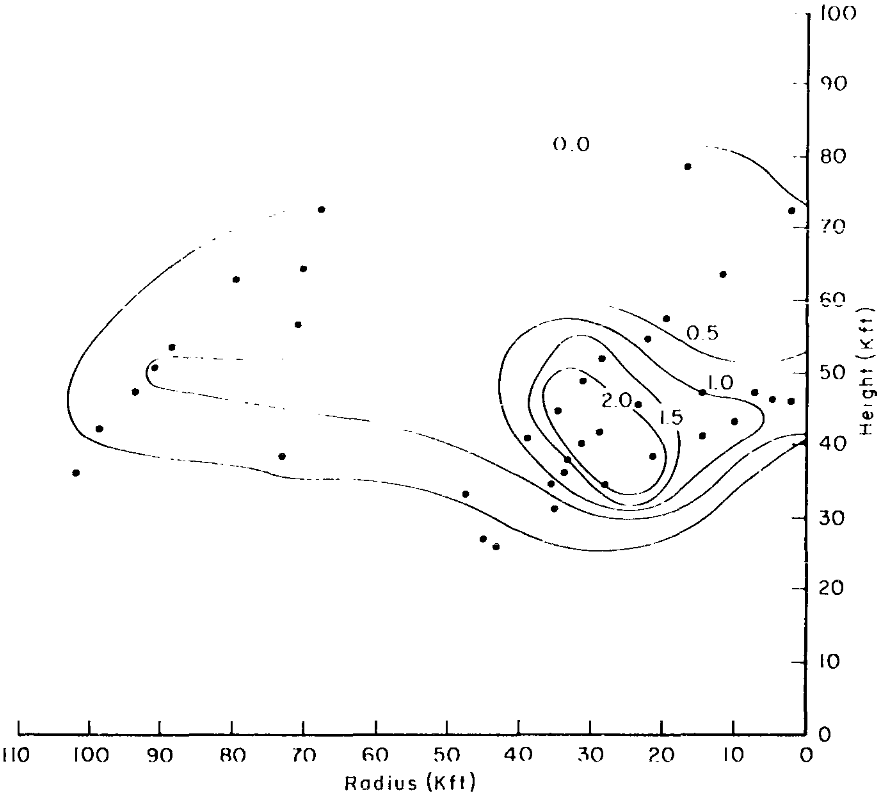


Fig. 5—Results of Zuni rocket measurements (a) at 7 min with subjective isopleths

Table 2

Debris Concentration (Fraction per Cubic Kilofoot x 10^5) from Rocket Results as a Function of Radius and Height

	Radius (kft)									
Height (kft)	5	15	25	35	45	55	65	75	85	95
5										
15										
25										
35		1.223	2.751	1.528	.489	.122				
45	.856	1.528	2.45	3.056	1.467	.795	.672	.672	.587	.489
55	.538	.562	1.223	1.589	.917	.611	.562	.550	.599	.306
65	.245	.306	.367	.428	.367	.306	.245	.061		
75	.061	.183	.245	.183	.122	.122				

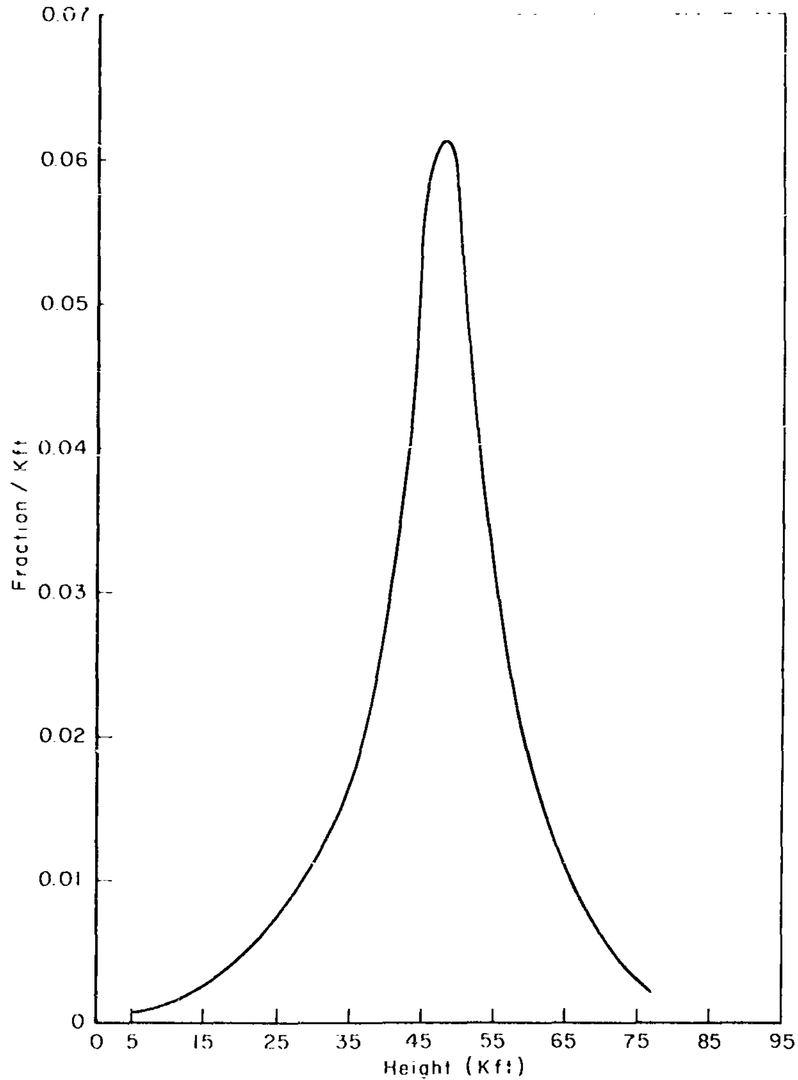


Fig. 6—Smoothed distribution of activity with height from Zuni rocket data

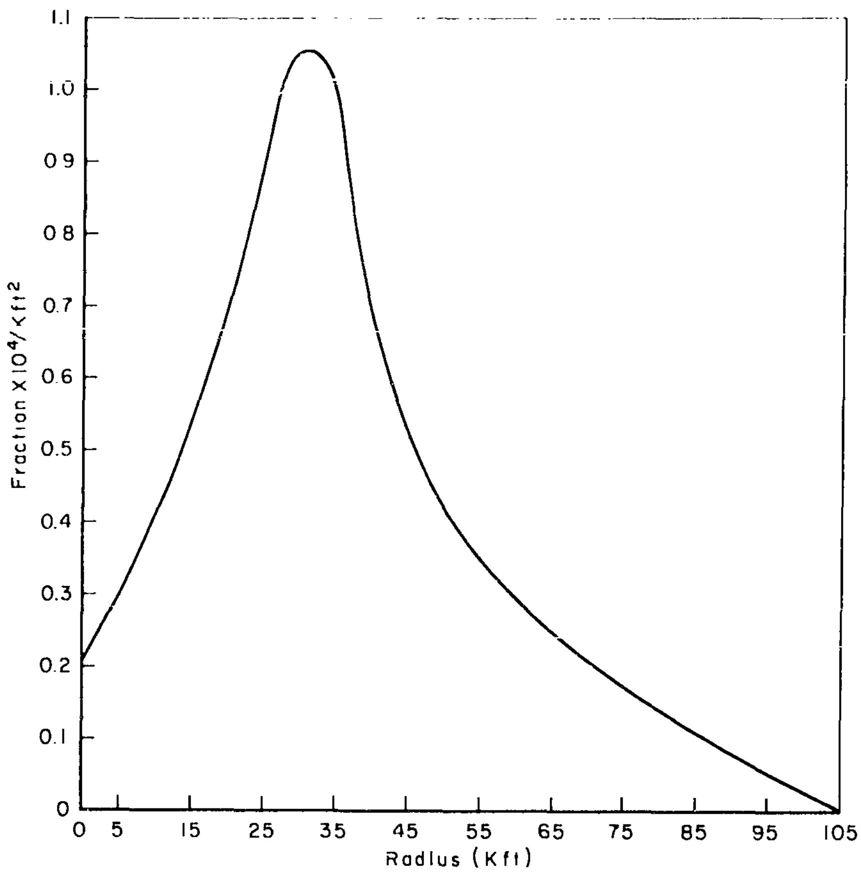


Fig. 7—Smoothed distribution of activity with radial distance from the cloud center from Zuni rocket data

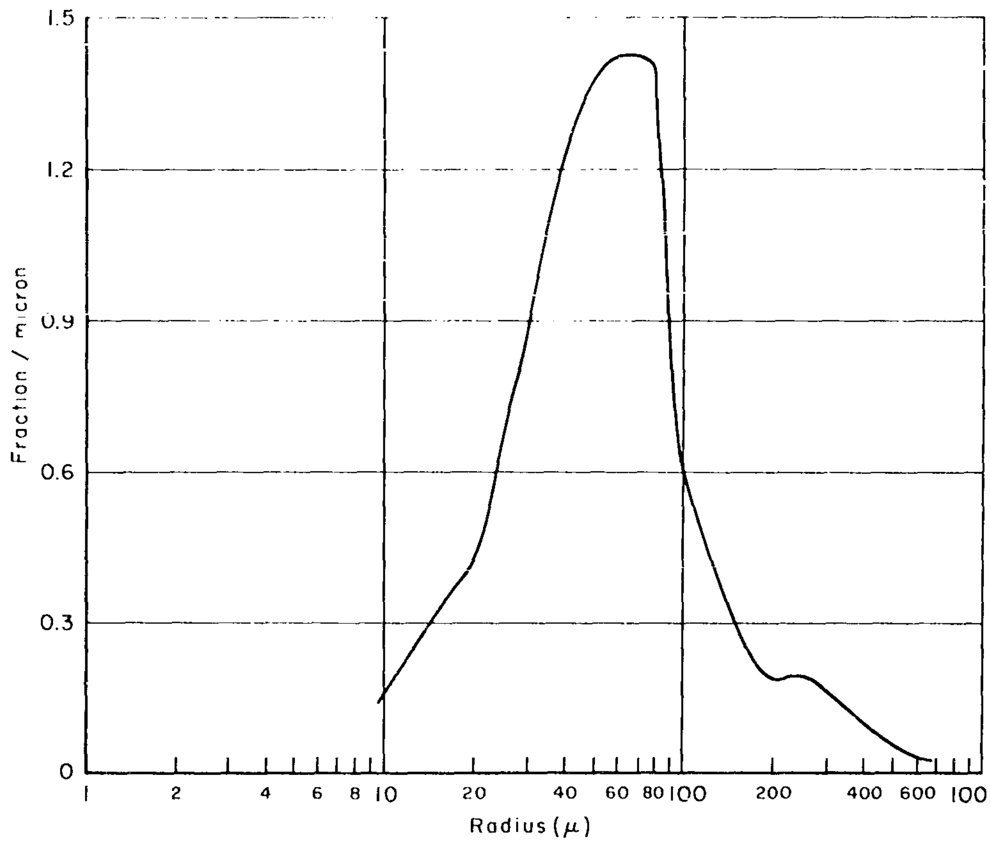


Fig. 8—Fraction of activity per micron as a function of radius of particle

IV. DISCUSSION

The initial test of the model, which will be referred to as "run 1," was made with the Castle-Bravo wind data taken from Dean and Ohmstead. The details are presented in the Appendix.

The ground position of a few selected particles, which were read from the results of the meteorological part of the computation, are shown in Fig. (9), which also shows the circular standard errors, derived from the discussion of meteorological errors, with the assumption of an error standard deviation, σ_{ϵ}, equal to 5 knots. It appears, from this figure, that random errors of this magnitude will not produce large errors in the orientation and general configuration of the pattern. It does seem reasonable to assume, however, that this type of error may cause a considerable error in the fraction of fallout at some point near the boundary of the fallout area. It must be emphasized that these wind error estimates do not include any gross error in defining the vector wind field.

Several variations of the activity functions were tried with the basic wind pattern of run 1. The purpose of these calculations was to make some qualitative estimates of the effect of changing the distribution functions. The details of these calculations are given in the Appendix and are referred to as run 1a, 1b, etc. The inferences which may be drawn from an inspection and comparison of the results of the calculations will be taken up in order.

The difference between runs 1a and 1b was only in the $A_1(r)$ function. The function used in 1b was a log-normal distribution with the same mean and standard deviation as the distribution shown in Fig. (6). The difference between the patterns is not striking. The 1b pattern is not as intense at the hot spot as the 1a pattern, but this was expected since the 1b pattern

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28

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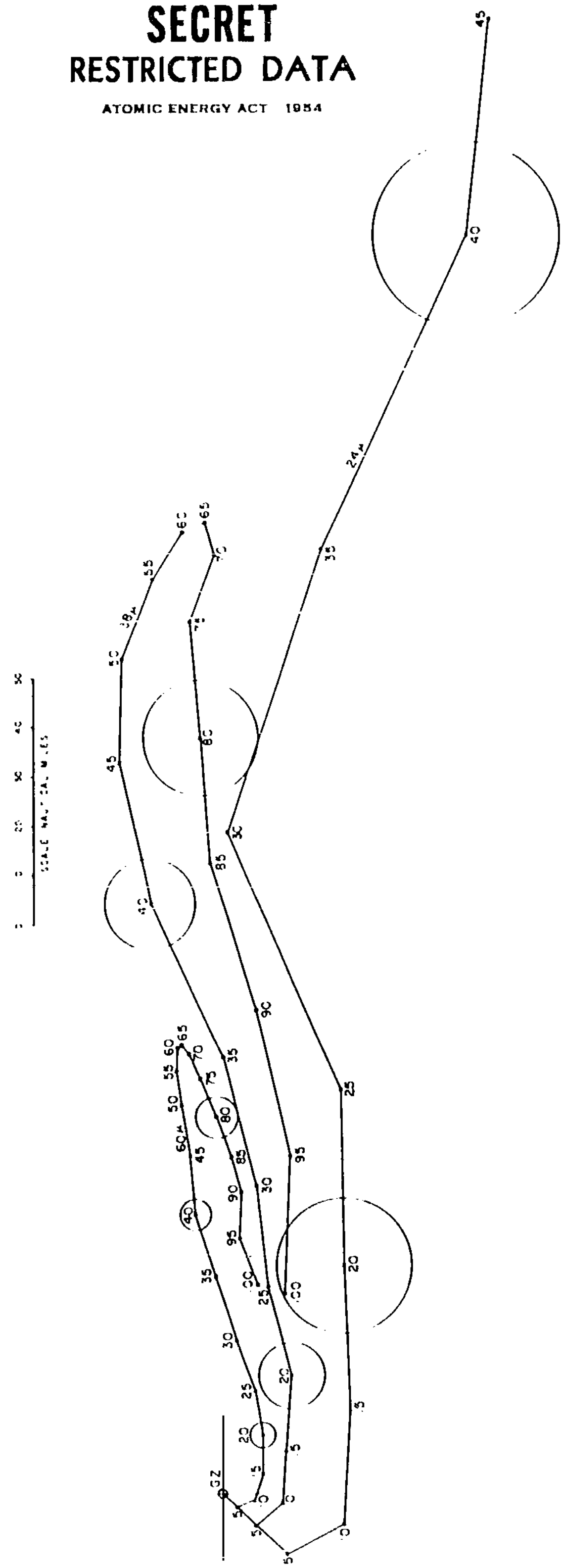

Fig. 9—Ground position and circular standard errors of selected particles

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had less material concentrated near the mean.

A comparison of runs a and b shows several interesting facts. The largest change is about 30 per cent at the point of maximum deposition in both of the patterns. The log-normal distribution of run 1b has fewer particles in the size below 55μ than does the RAND distribution of run 1a. The distribution used in run 1b also shows a higher close-in value than does the run 1a, indicating too much activity on larger particles.

A comparison of both of these runs with the fragmentary data of the Castle-Bravo shot brings two facts to light. The first point is that both the 1a and 1b distributions show far too large a fraction on the islands of the Bikini Atoll. The second point is that values are low in the northern part of Rongelap.

These errors may be due to an incorrect wind analysis, but they could also be explained by a set of incorrect distribution functions. In any event, the relatively slight change in the patterns between an empirical distribution and a mathematical model seems to be slight. This suggests that an attempt could be made to fit the best possible log-normal, or any other useful function, to the existing data.

Runs 1c and 1d were made to note the comparison of the old model with the new. Run 1c was the mushroom portion, and run 1d was the stem; together they reproduce a pattern with essentially the same assumptions as the old RAND model. The pattern for run 1c, the mushroom portion, again shows relatively slight differences from runs 1a and 1b. The addition of the stem material from run 1d makes little change in the pattern. The greatest contribution from the stem is near ground zero, which is already too high, and near the perimeter of the pattern where the uncertainty is greatest.

A rather drastic change in the distribution of activity with size was made in run 1e. The amount of activity on particles greater than 95μ radius was halved, and this excess was added to the particles between 35μ and 65μ in radius. This run used the same spatial distribution as runs 1a and 1b. The "hotspot" for run 1e was moved far away from ground zero and was reduced in intensity.

V. CONCLUSIONS

Since the observations on Castle-Bravo were fragmentary, there is no useful purpose to be served by continuing variation of parameters on the set of winds from this shot. The work done has proven the feasibility of the approach and has verified the accuracy of the model within the limits of the available data. It is believed that the next set of data processed can proceed on the assumptions that:

1. small changes in the distribution functions will produce only negligible changes in the pattern;

2. the wind patterns are sufficiently accurate to put limits on the possible distribution functions;

3. the gross effects of the fallout from large-yield shots are not affected by stem material.

It may be inferred that most of the material is lodged on particles in a very narrow range of sizes and that it is concentrated into a very narrow range of heights at the time of stabilization.

The next set of runs will be made on the Zuni shot of Operation Redwing. An attempt will be made to adjust the distribution functions so as to produce calculated values of the fraction-down which are within the range of error measurement at those stations for which adequate measurements are available. This then will be assumed to be the optimum model, and the errors of this model will be assumed to be a minimum for fallout calculations.

APPENDIX

A. METEOROLOGICAL DATA

Run 1 refers to those fallout calculations that were based on the winds at the time of the Castle—Bravo event. The winds were read from the Dean and Ohmstead charts at 8 locations. Table A1 gives these locations in terms of N-S and E-W distances from ground zero. It was necessary to insure that there were no three points which could be simultaneously colinear and closest to the falling particle, because this situation would invalidate the interpolation functions. The winds were read at two different times (8.25 hours and −15.75 hours from H hour). For times longer than 8.25 hours the wind was assumed to be invariant with time. Table A2 lists the winds at the eight points at two different times.

Table A1

Positions of Points, Relative to Ground Zero, Where Wind Information was a Machine Input

Point	Distance East (n mi)	Distance North (n mi)
A	− 14	50
B	136	50
C	286	100
D	436	50
E	− 14	−100
F	136	−100
G	286	− 50
H	436	−100

Table A2a

Wind Values for Run 1
at 15.75 Hours before Shot Time

Elevation (ft)	Position* A V	A α	B V	B α	C V	C α	D V	D α	E V	E α	F V	F α	G V	G α	H V	H α
5,000	07	45	09	52	09	92	10	85	09	75	13	55	14	254	10	040
10,000	18	305	11	330	13	170	12	130	15	265	10	310	05	350	05	290
15,000	12	265	11	280	13	214	8	210	12	248	10	289	07	297	09	250
20,000	16	220	17	250	18	240	18	250	10	220	12	270	13	230	14	250
25,000	22	233	23	250	23	243	24	250	16	226	17	238	15	255	20	241
30,000	28	240	29	250	29	245	29	250	22	230	25	225	20	240	25	235
35,000	28	244	29	254	30	253	32	257	22	233	25	233	21	249	27	247
40,000	27	250	29	258	31	259	35	264	23	237	25	241	24	253	29	256
45,000	27	255	30	262	33	265	39	266	24	242	26	248	27	255	33	254
50,000	27	260	30	265	35	270	42	270	24	245	27	255	30	270	37	270
55,000	20	264	22	269	25	274	33	273	16	246	18	259	20	275	27	273
60,000	12	265	24	278	18	283	23	279	08	250	11	268	13	286	17	279
65,000	02	285	08	302	11	302	14	294	01	349	02	310	07	330	08	299
70,000	03	50	07	08	08	335	08	335	09	54	07	42	08	025	06	025
75,000	12	67	12	42	13	40	12	35	17	59	15	56	15	30	14	062
80,000	20	70	20	55	20	55	20	55	25	60	23	60	22	60	23	70

* V = Speed (kn)
α = Direction (10's of degrees from N)

Table A2b

Wind Values for Run 1
at 8.25 Hours after Shot Time

Elevation (ft)	Position*															
	A		B		C		D		E		F		G		H	
	V	α	V	α	V	α	V	α	V	α	V	α	V	α	V	α
5,000	09	015	06	110	06	100	08	088	09	062	08	075	10	070	09	054
10,000	12	340	10	270	07	280	06	320	10	270	05	230	05	330	05	315
15,000	16	303	14	283	12	302	11	317	13	277	08	304	09	343	06	317
20,000	23	285	19	290	17	310	17	315	17	280	16	320	13	340	10	320
25,000	29	275	25	271	20	271	16	265	18	244	15	264	11	250	13	234
30,000	35	270	34	250	30	250	29	230	25	220	25	230	25	220	25	215
35,000	40	264	41	250	39	253	38	246	32	220	33	236	33	233	30	236
40,000	45	260	46	250	49	255	49	255	39	220	42	240	42	240	39	250
45,000	38	266	44	265	45	266	48	258	23	212	23	251	29	262	37	273
50,000	32	275	40	270	43	275	50	280	10	180	10	310	25	300	41	295
55,000	19	276	24	270	27	272	32	275	03	214	08	288	17	285	27	284
60,000	06	280	08	270	12	260	15	260	07	330	08	260	12	260	17	250
65,000	04	014	03	345	11	288	06	278	08	039	02	044	03	315	05	296
70,000	11	050	09	046	07	005	06	034	15	062	11	066	10	055	10	042
75,000	18	057	17	057	15	050	16	055	24	071	21	069	20	065	22	055
80,000	25	060	25	060	25	060	25	060	32	075	30	070	30	065	34	060

*V = Speed (kn)
α = Direction (10's of degrees from N)

B. GEOMETRIC DATA

Run 1a

In order to adjust the geometric distribution functions A_2 and A_3 to to the yield of the Castle-Bravo event, it is necessary to spread the debris over a larger region of space. Since the integrals of the A functions must equal 1, the actual activities must be reduced accordingly. According to Kellogg[10] the cloud diameter of a 3.5 MT device is $\sim$20 n mi and a 15 MT device is $\sim$ 29 n mi. Since the Zuni distribution of $A_3(R)$ reduced to nearly zero at $\sim$17 n mi (see Fig. 8), it was scaled up to $\sim$24 n mi for the Castle-Bravo shot. The activity A_3 was therefore reduced. In a similar way the height of the cloud was increased, and the activity fraction A_2 was decreased.

All of the values of A were tabulated to such a degree that linear interpolation caused less than 1 per cent in the difference between the curves and the interpolated values. The tabulated distribution functions are shown in Table A3.

The machine output gives the fraction of device per square kilofoot at a number of pre-chosen points. The results of this calculation for run 1a are shown in Fig. A1. The isopleths that are drawn on Fig. 9, are subjective estimates of the lines of equal fraction down.

Run 1b

The conditions for run 1b are the same as for run 1a except for the distribution of activity with particle size. The distribution used in run 1b is the log-normal distribution with the same mean and standard deviation as the distribution in run 1a. Table A4 shows the values of $A_1(r)$ as a function of r and also the differences between $A_1(r)$ for run 1a and $A_1(r)$

Table A3

Activity Function for Run 1a

h (kf)	$A_2(H)$	r(μ)	$A_1(\ln r)$	R(n mi)	A(R) x 10^{-4}
0	0	9.5	0.15	0	.102
5	.00024	12.25	0.24	.822	.138
10	.00068	15.0	0.33	1.645	.174
15	.00140	20.0	0.41	2.467	.211
20	.00240	24.0	0.66	3.289	.260
25	.00376	31.0	0.93	4.112	.316
30	.00544	38.0	1.19	4.934	.385
35	.00760	49.0	1.37	5.757	.456
40	.01040	60.0	1.42	6.579	.688
45	.01464	77.5	1.41	7.401	.764
50	.02200	95.0	0.68	8.224	.495
55	.03560	123.0	0.43	9.046	.372
60	.04904	151.0	0.27	9.868	.303
65	.03624	195.0	0.19	10.691	.252
70	.00280	239.0	0.20	11.513	.218
75	.01456	309.0	0.16	12.336	.191
80	.00976	379.0	0.11	13.158	.169
85	.00632	489.0	0.06	13.980	.151
90	.00384	600.0	0	14.803	.131
95	.00208			15.625	.117
100	.00128			16.447	.102
				17.270	.089
				18.092	.076
				18.914	.065
				19.937	.054
				20.559	.044
				21.382	.033
				22.204	.023
				23.026	.014
				23.849	.005

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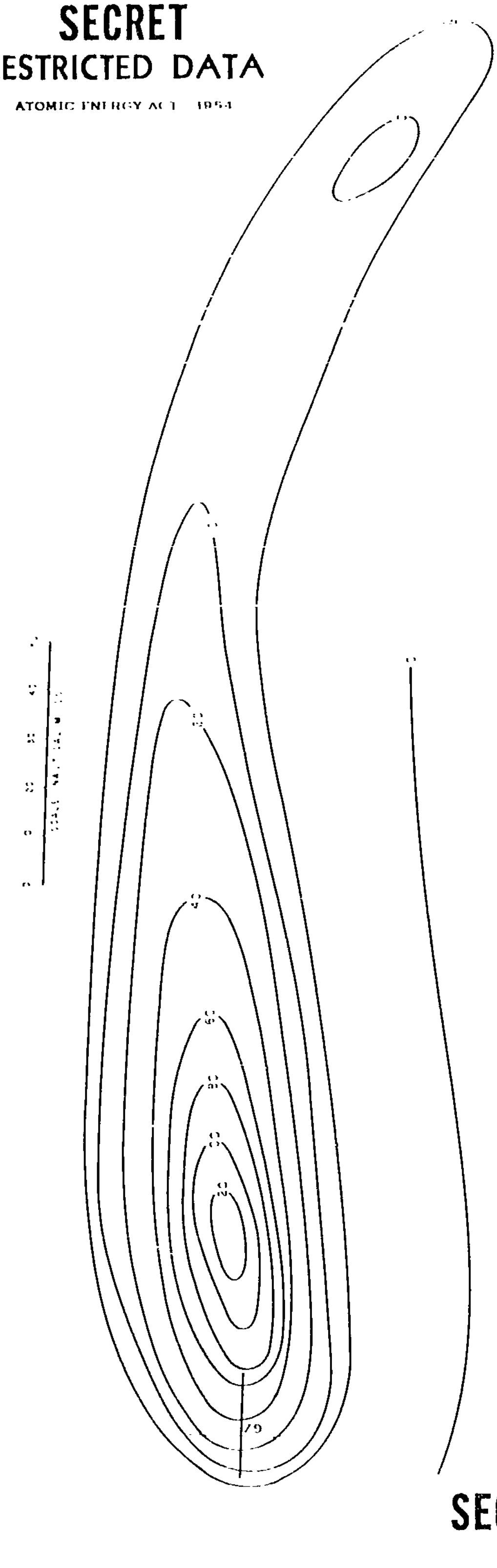

Fig. A-1—Run 1a, results of calculation
(Fraction of device/Kft X 10^7)

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for run 1b. Figure A2 shows the fallout computation for run 1b with isopleths subjectively drawn.

Table A4

$A_1(r)$ for Run 1b as a Function of (r),
and the Difference between A_1 for Run 1a and A_1 for Run 1b

Index	r	$A_1^b(r)$	$A_1^a - A_1^b$
1	9.5	.280	-.13
6	12.25	.389	-.15
11	15.0	.520	-.19
16	20.0	.648	-.24
21	24.0	.767	-.11
26	31.0	.865	.07
31	38.0	.918	.21
36	49.0	.928	.44
41	60.0	.883	.54
46	77.5	.800	.61
51	95.0	.685	.00
56	123.0	.559	-.13
61	151.0	.427	-.16
66	195.0	.310	-.12
71	239.0	.214	-.01
76	309.0	.140	.02
81	379.0	.086	.02
86	489.0	.051	.01
91	600.0	.028	.03

Run 1c

In order to be able to check the effect of the A(R) and A(H) distributions a model was set up which was similar to the model discussed in reference (1). The exponential decrease with height was assumed for the mushroom and the invariant distribution with R was retained. However 97 per cent of the activity was put into the mushroom, instead of 90 per cent as in the earlier model, and the remaining 3 per cent was used to make up run 1d. The input values are shown in Table A5 and the final pattern is shown in Fig. (A3).

RM-2115
2-13-58
40

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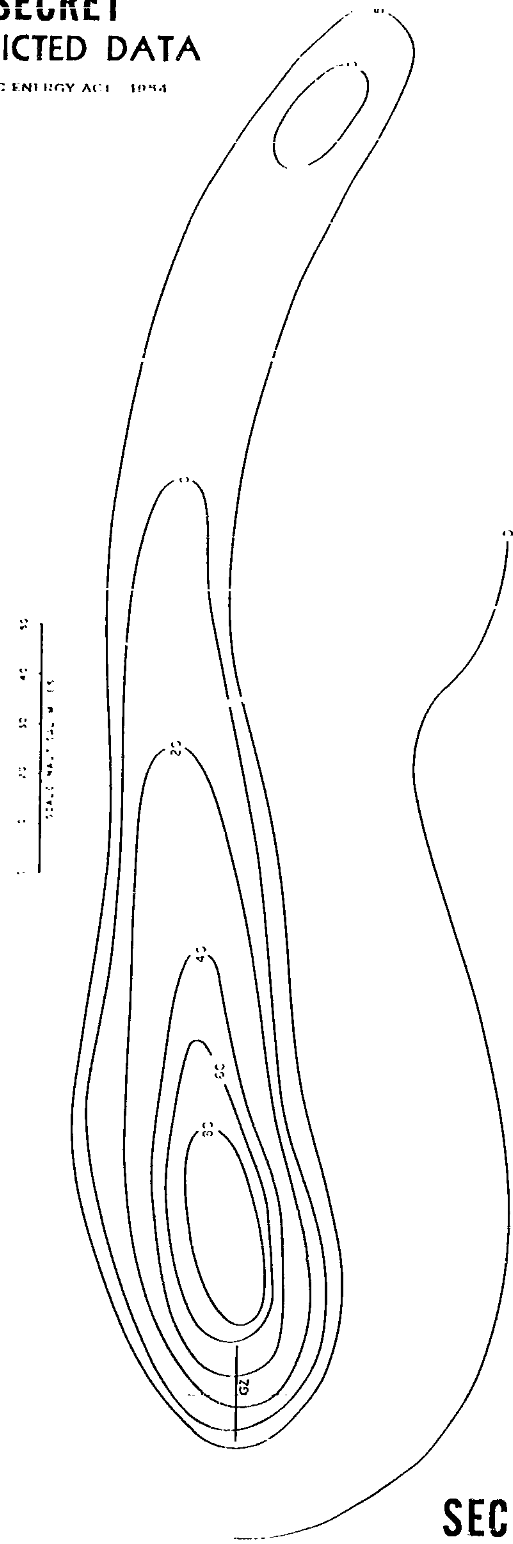

Fig. A-2—Run Ib, results of calculations
(Fraction of device/Kft X10^7)

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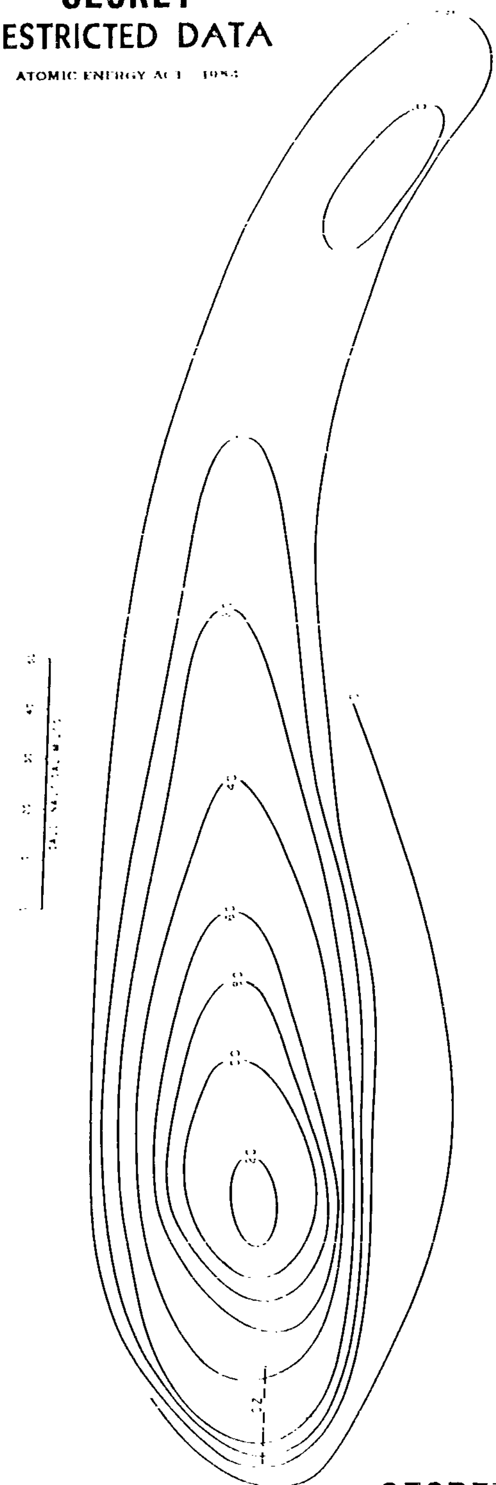

Fig. A-3 — Run 1c, results of calculations
(Fraction of device/Kft $\times 10^{7}$)

Table A5

Activity Distribution for Run 1c

r	$A_1(r)$	R	$A_3(R)$	h	$A_2(H)$
9.5	0.1455	0	3.513×10^{-5}	0	0
12.25	0.2328	.822	3.513×10^{-5}	5	0
15.0	0.3201	1.645	3.513×10^{-5}	10	0
20.0	0.3977	2.467	3.513×10^{-5}	15	0
24.0	0.6402	2.467	3.513×10^{-5}	20	0
31.0	0.9021	2.467	3.513×10^{-5}	25	0
38.0	1.1543	2.467	3.513×10^{-5}	30	0
49.0	1.3289	2.467	3.513×10^{-5}	35	0
60.0	1.3774	2.467	3.513×10^{-5}	40	0
77.5	1.3677	2.467	3.513×10^{-5}	45	0
95.0	0.6596	2.467	3.513×10^{-5}	50	0
123.0	0.4171	2.467	3.513×10^{-5}	55	0.00560
151.0	0.2619	2.467	3.513×10^{-5}	60	0.04394
195.0	0.1843	2.467	3.513×10^{-5}	65	0.03472
239.0	0.1940	19.737	3.513×10^{-5}	70	0.02743
309.0	0.1552	20.557	0	75	0.02167
379.0	0.1067	20.557	0	80	0.01712
489.0	0.0582	20.557	0	85	0.01353
600.0	0	20.557	0	90	0.01069
		23.849	0	95	0.0084
				100	0.0067

Run 1d

This run was merely the stem portion of run 1c. The total fraction placed in the stem was only 3 per cent, and the addition of this fallout to run 1c made only minor changes in the pattern. In order to get the gross effects of the fallout, it appears unnecessary to be concerned with the stem. In fact even this small amount of stem fallout seemed to increase the error in the pattern in those areas wherein it was detectable.

Run 1e

This computation was designed to make a more radical change in the distribution function in order to produce a greater change in the pattern. Since the previous attempts indicated that there was too much debris too close to ground zero, the activity on the larger particles was drastically reduced. The activity size distribution of run 1e is shown in Table A6 and the resulting pattern is shown in Fig. (A4). It may be noted that the activity is spread further down-wind than in the other runs, although the maximum has been considerably lowered.

Table A6

The Function $A_1(r)$ for Run 1e

Index	r	$A_1(r)$
1	9.5	0.15
6	12.25	0.24
11	15.0	0.33
16	20.0	0.41
21	24.0	0.66
26	31.0	0.93
31	38.0	1.59
36	49.0	1.77
41	60.0	1.56
46	77.5	1.31
51	95.0	0.34
56	123.0	0.22
61	151.0	0.13
66	195.0	0.10
71	239.0	0.09
76	309.0	0.08
81	379.0	0.05
86	489.0	0.03
91	600.0	0

RM-2115
2-13-58
44

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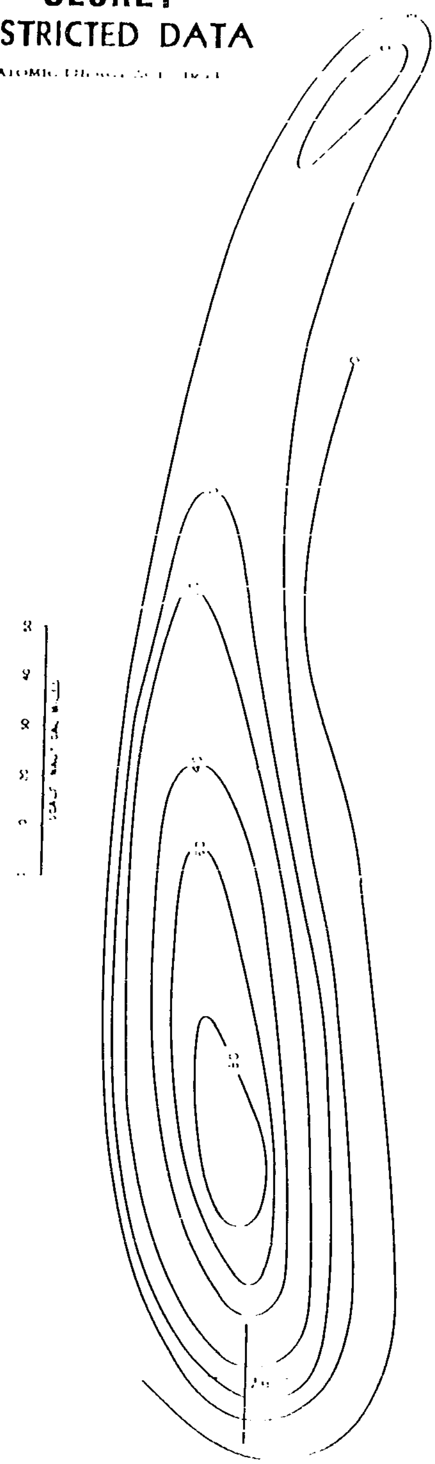

Fig. A-4 — Run Ie, results of calculations
(Fraction of device/Kft × 10^7)

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47

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50

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A NEW MODEL FOR FALLOUT CALCULATIONS (UNCLASSIFIED TITLE), by R. R. Rapp, Research Memorandum RM-2115, February 13, 1958, Secret-Restricted Data (Limited Distribution). 55 pp. incl. illus., references.

A new model for the machine calculation of fallout patterns. The model is divided into meteorological, geometric, and radiological parts which consider respectively 1. the wind velocity and the fall velocity of the particles, 2. the distribution of activity on particles in the cloud as a function of height and particle size, and 3. the radiation doses of particles on the ground. The use of the model is illustrated, and the changes in the model that will provide an optimum model (currently being developed) are discussed. (Unclassified abstract)

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Defense Threat Reduction Agency
45045 Aviation Drive
Dulles, VA 20166-7517

CPWC/TRC May 6, 1999

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- DASA-1298, AD-285252, STATEMENT A
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- DASA-1271, AD-276892, STATEMENT A
- DASA-1279, AD-281597, STATEMENT A
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- DASA-1245, AD-419911, STATEMENT A
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- ~~DASA-1283, AD-717097~~, STATEMENT A OK
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- DASA-2627, AD-514934, STATEMENT A
- DASA-2651, AD-514615, STATEMENT A
- ~~DASA-2536, AD-876697, STATEMENT A~~
- DASA-2722T-V3, AD-518506, STATEMENT A
- DNA-3042F, AD-525631, STATEMENT A
- DNA-2821Z-1, AD-522555, STATEMENT A

If you have any questions, please call me at 703-325-1034.

Ardith Jarrett

ARDITH JARRETT
Chief, Technical Resource Center